Basin Acoustic Seamount Scattering Experiment (BASSEX) Data Analysis and Modeling

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LONG-TERM GOALS

In this program we are focusing on the science issues associated with long range ocean acoustic propagation in range-dependent environments. The primary goal is to understand the physics of the acoustic propagation in complex environments. Three specific propagation regimes are the focus of this work: 1.) seamount scattering, 2.) open ocean propagation and 3.) downslope propagation in a strongly range-dependent environment. The long-term goal is understand scattering off of seamounts and island slopes and to develop algorithms for modeling the acoustic field in these severely range dependent (and azimuthally anisotropic) environments.

In the 2004 BASSEX experiment, with Chief Scientist Professor Arthur Baggeroer (MIT) and Co-Chief Scientist Dr. Kevin Heaney (OASIS), several specific areas of acoustic propagation where addressed. During the test acoustic transmissions from sources used in the SPICEX and LOAPEX experiments (PI: Dr. Peter Worcester, SIO and Dr. Jim Mercer, APL-UW), were recorded in the central Pacific using the Office of Naval Research – Five Octave Research Array. One week of this test was devoted to seamount scattering, with many receptions taken in various scattering geometries around the Kermit-Roosevelt seamount complex. A second week was spent in transit recording open ocean transmissions at ranges of 250km through 2000 km. The final week was spent off the coast of Kauai, recording the NPAL Kauai source at various ranges and bearings.

OBJECTIVES

The primary objective of this work is to measure aspects of acoustic propagation that we do not currently understand well (backscattering, effects of bottom roughness, propagation over basalt, 3D propagation, refraction and healing behind a sea-mount), to develop physical intuition from the data and formulate a numerical and theoretical approach to model such phenomena. The objective for this year’s effort has been to perform preliminary data analysis and to develop an understanding, through data-model comparisons, of where our physical intuition and understanding is lacking.

APPROACH

Our proposed technical approach is a multi-stage approach to signal processing of the measured data and comparison with acoustic simulations. The first step is to apply beamforming and matched filtering to all of the data. This pass was done to determine a set of receptions that contain interesting physical phenomenon for further study. Once these sets are determined, plane wave and parabolic equation (PE) modeling of the geometry associated with these receptions is performed and a detailed

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comparison of the prediction (using 2D propagation) and the measurement is performed. Once this step is completed, effects of bottom roughness, shear in the sediment and 3D propagation will be studied.

WORK COMPLETED

In the past year all of the BASSEX04 data has been processed. The processing has consisted of both element level matched filtering and beam based matched filtering. Due to motion of the receiver (it is a towed array) a search in doppler must be conducted during the matched filter process. This search was completed and received arrival patterns were computed for each reception. From this data-set of processed receptions, a collection of scientifically interesting receptions was assembled. These receptions addressed the issues of 3D propagation, downslope conversion, seamount geo-acoustics and Kauai geo-acoustics, long-range open water transmissions and seamount scattering.

Current acoustic modeling work consists of ray-tracing in open water and broadband Parabolic Equation modeling for downslope and seamount environments. The PE modeling is only 2D and one of the significant results to date is how poor the 2D PE does at reproducing the narrowband complexity (eigenvalue distribution) of the received signal.

Geo-acoustic inversion work has been performed for the BASSEX04 receptions that are near the NPAL Kauai source. This has led to the conclusion that the seafloor near Kauai is lossy. Geo-acoustic inversion algorithms have characterized this loss by determining a geo-acoustic sediment that is thick and contains soft sediment (hence the high-attenuation). This raises a dilemma. We do not think that the sediment off Kauai is thick and soft. Another possibility, which we are exploring now, is that bottom roughness is the source of the high attenuation.

Several receptions near Kauai show significant 3D propagation. One reception, which was surprising, shows strong arrivals coming in 30 degrees behind the direct path (at broadside) in a region where we only expect a direct path (consisting of many multi-paths). Further examination of the bathymetry indicates that sound could be scattered from the rubble field located off the north-west coast of Kauai.

The feasibility of performing Moving Ship Tomography (MST) with towed array and fixed sources was examined. The open water portion of the BASSEX04 test was used as an initial data-set. Sound was received on the FORA array as the R/V Revelle passed between the two SLICE moorings (4 sources), which were transmitting simultaneously. The resolution of the data, in particular the ability of the array to separate receptions from each SLICE source, was very promising. It was demonstrated, numerically, that the range and depth diversity of the recordings permitted an inversion for the general range dependent ocean characteristics in the region. This result, however, was contingent on both array location knowledge and accurate receiver timing. The array localization approach for the BASSEX04 array is currently using only a simple model and has ~100m accuracy. There have also been questions raised about the accuracy of the FORA timing. These two issues severely limit the ability to perform tomographic inversions from this dataset. It is hoped that both of these technical issues can be resolved prior to the next test and MST can be accomplished with a towed array as a receiver.

RESULTS

1. Geo-acoustic inversion over range-dependent basalt

The region near Kauai has been of significant importance to the long range acoustics community because of the placement of the NPAL Kauai source. Bathymetric interaction was studied in Vera and Heaney[1], and in Heaney[2]. Prior to understanding three-dimensional propagation effects and downslope propagation evolution of the signal into deep water, an accurate geo-acoustic model must be determined. During the BASSEX sea-test at least 4 receptions were recorded within 10 km of the Kauai source primarily for the purpose of geo-acoustic inversion. Inversion results to-date (Figure 1) indicate a thick-sediment (H>200m) of sand/silt.

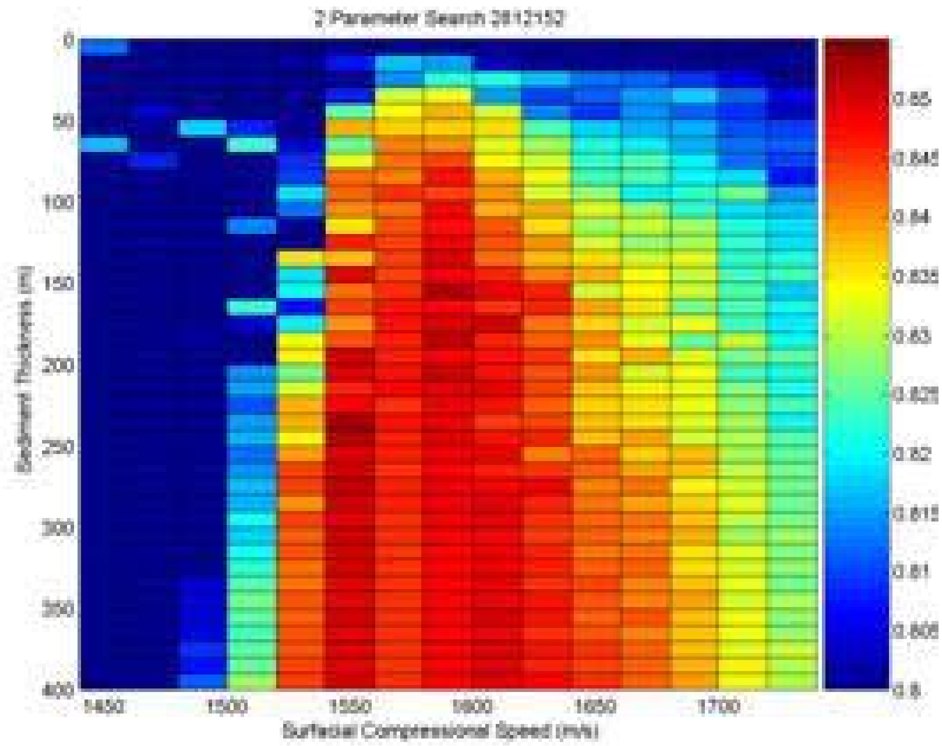

Figure 1 – Cost function for geo-acoustic inversion from 2-4 km Kauai Transmissions.

This inversion is based upon a 2 parameter brute-force search of a simple time-domain cross-correlation (after searching on optimal range) of the received and PE modeled signal at for a single transmission (40 periods) extending from a range of 2-4 km. Future inversion work will be based upon striations for the frequency band 5Hz-120Hz and a matched-field based genetic algorithm inversion. To date there have been no indications that shear in the basalt is a dominant physical process – though it may turn up as an anomalous attenuation.

2. 3-Dimensional Propagation and Environmental Uncertainty in Acoustic Propagation

During several receptions of the NPAL Kauai source, during the BASSEX experiment evidence of 3D propagation was observed. Some of these are for understandable geometries where propagation is along the coast of the island of Kauai and the sloping bathymetry is expected to lead to horizontal refraction. Others, including those shown in Figure 2, show strong 3D arrivals for paths that are down-

slope into deep water. Clearly sound is "scattering" from outside of the horizontal plane, arriving at the array from a different bearing. Further analysis will include processing all of the BASSEX KNPAL receptions and performing 3D acoustic propagation modeling with a 3D PE to see if we can reproduce the observations.

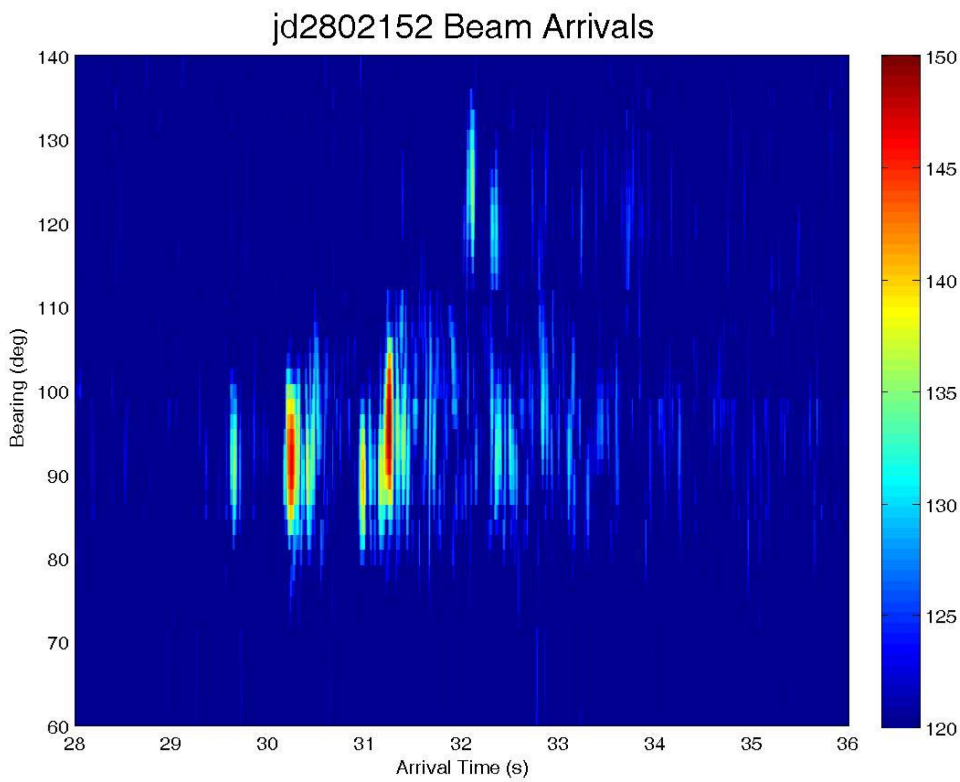

Figure 2 – Beam time series from a deep water reception. Stable, identifiable arrivals are observed on the array with an incedent angle of 130 degrees when the direct blast (including all of it's multipath) is coming in at 90.

3. *Geo-acoustic inversion of deep water seamount from forward scattering*

One of the issues associated with seamount scattering, as well as complex noise modeling of the basin-scale noise field is the depth of the sediment cover of open ocean seamounts. The sediment in the abyssal ocean is expected to be up to several kilometers in depth, but it is thought that currents, which increase near seamounts due to upwelling, will strip off the sediment as the seamount rises from the depths. In the BASSEX seamount scattering portion of the experiment we have several receptions recorded directly above two seamounts. In these receptions, there is clearly a direct, all-water path arriving at the array, as well as a reflection from the seamount, coming up from below. Through PE modeling, we will investigate the effect of sediment thickness on the received signal, and we expect to determine a rough order of magnitude of the sediment thickness.

4. *Evolution of sound field propagating downslope into deep water*

In the BASSEX data-set there are 10-20 receptions of the Kauai NPAL source taken from ranges of 1 km to 250 km as the R/V Revelle approached the island of Kauai. The evolution of the broadband acoustic pulse as it propagates down the slope of Kauai into deep water is of importance to the

oceanographic community (tomographic input signals from shallow moored sources) the navy (deep water detection of shallow water submarines and vice-versa) and the nuclear test-ban verification people. Through PE modeling and data-comparison (with both the BASSEX array data, and the vertical line array data collected from the SPICE array, at a range of 3200 km) we expect to be able to explain the effects of bottom interaction and to predict the evolution of the pulse.

5. *Single Transect Moving Ship Tomography*

31 receptions were taken on the BASSEX cruise as the array passed between the two SPICE arrays. The geometry of this single slice (between two sources) is shown in Figure 3. This single path, with all recordings taken while underway, provides a test of the single slice Moving Ship Tomography (MST) approach. The approach is contingent upon accurate array element localization. We believe that if we can localize the array to within a few meters, utilizing the ADCP current data and a Kalman filter approach to the array hydrodynamics, we will be able to perform 3D ocean acoustic tomography from the ship. The development of this technique is important for the future of synoptic ocean acoustic tomography.

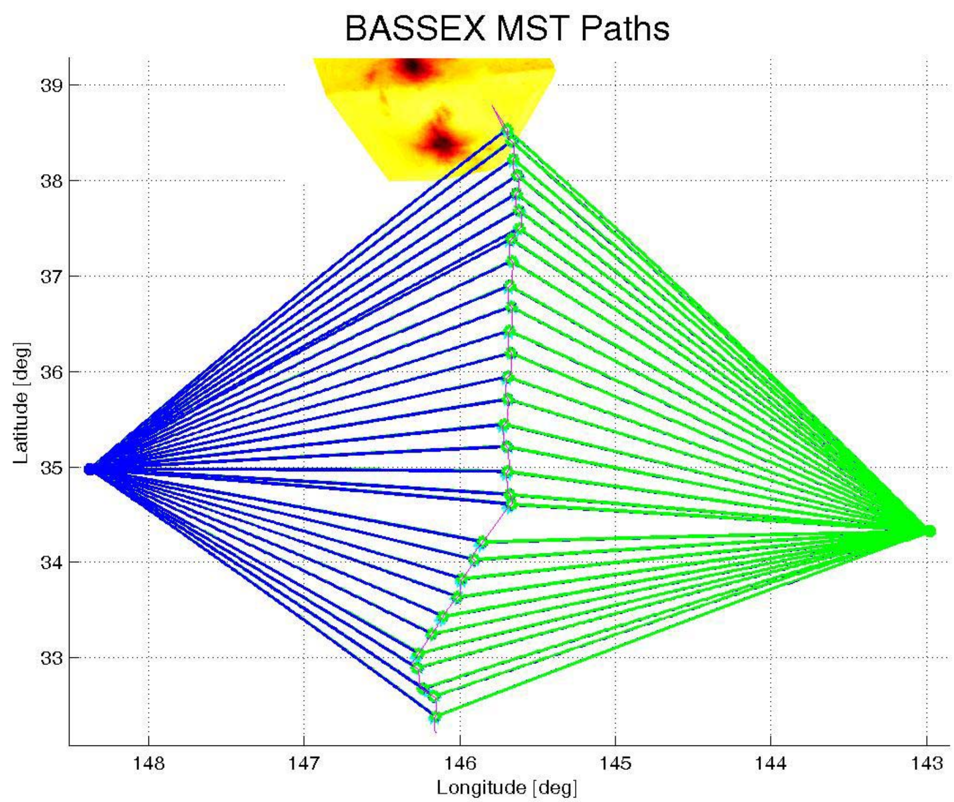

Figure 3 – Geometry of receptions taken during the BASSEX04 cruise, as the R/V Revelle passed between the two SPICE source moorings.

IMPACT/APPLICATIONS

Many sites of potential tactical naval interest exist in the world where there is strong downslope range-dependence and the presence of rough bottoms that have shear wave propagation. With a systematic approach to data analysis, data-model comparison and theoretical development it is expected that a better capability of modeling acoustic propagation in this difficult environment will be arrived at.

RELATED PROJECTS

The SPICEX and LOAPEX experiments where conducted at the same time as the BASSEX experiment, as the other two parts of the North Pacific Acoustic Laboratory (NPAL 04) sea-test. The SPICEX experiment transmitted broadband signals with a center frequency of 250 Hz from two source moorings located a distance of 500 and 1000 km away from a vertical line array mooring. The science to be investigated during this test is the scattering of acoustic energy in the mixed layer. An understanding of the combination of acoustic scattering in the mixed layer, and mixed layer oceanography is sought through this data set. The LOAPEX experiment transmitted broadband signals centered at 75Hz from ranges of 50, 250, 500, 1000, 1600, 2300, 3200 km to the same vertical line array. An understanding of the dependence upon range of the effects of internal wave scattering is sought through this data set.

REFERENCES

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PUBLICATIONS

1. Heaney, K.D. and A.B. Baggeroer. *Measurements of 3-dimensional Downslope Acoustic Propagation During the Basin Acoustic Seamount Scattering EXperiment (BASSEX-04)*. in *Oceans Asia*. 2007. Singapore: IEEE.